# Laser Diode Control System

**Team Members:**

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**Supervising Professor:**

Dr. Jorge Rocca

**Summary:**

In the Extreme Ultraviolet Engineering Research Center (EUV ERC), diode pumped lasers are being used to create a soft x-ray laser that will be used in many future applications. Diode pumped lasers require a controller to manipulate the voltage and current the diode receives. Currently, there are controllers that provide a regulated voltage and current to supply the diode with enough power to create a laser. The goal is to implement a new, updated diode controller to reduce the effects of high frequency noise and increase the amount of protection on each of the controller circuit boards. New features, software, and box layout will be implemented along with possible redesigns of board level circuitry. The final goal includes installing five stable, noise-resistant controllers to control ten different laser diodes.

**Importance of Project:**

The initial goal set by Dr. Rocca was to create a diode pump soft x-ray laser with a 1 kHz repetition rate. At this high of a repetition rate, fast switching becomes an obstacle to the current controller due to an increase in electromagnetic noise from not only the controller itself, but also all of the components in the laser system. The controller will be able to handle the increased repetition rate while also being almost immune to the noisy environment.

**Problem Statement:**

Laser diodes require very precise voltages and currents to create a laser. An unexpected shock to the boards or slight variation in the output current can result in damage of very sensitive and expensive equipment. The greatest concern is keeping any of these scenarios from happening.

**Objectives:**

The objective is to design a controller that can precisely control output and simmer currents while also being able to monitor the status of different components within the system. Controller stability is key in the design. If any hardware or software fails because of interference from noise, inside or outside the box, valuable equipment could be damaged and destroy key components within the system.

There are two systems that these controllers will be manipulating, Quasi-Continuous Wave (QCW) and Laser Diode Driver/High Powered Pulser (LDD/HPP) systems. Figure 1 shows how the entire system will come together.

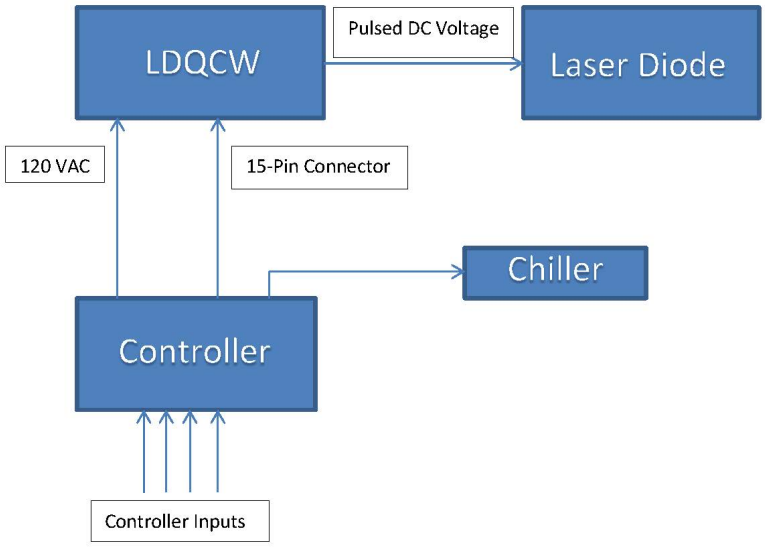


**Figure 1: QCW Laser Diode System**

The controller that will be developed and assembled will power the QCW while also controlling the output current the laser diode sees. Chillers are used to cool parts of the laser system. Although the QCW controller will not be powering the chiller, it will be connected to it via an interlock. If there are any errors in the flow or level of the chiller, the interlock will trip and cause the system to shut down. Signals are sent to and from the controller and QCW through a 15-pin DSUB connector. Other interlocks for different parts of the laser system will be connected to the controller for further protection of the system. Figure 2 illustrates the basic design and implementation of the controller in the LDD/HPP laser system.

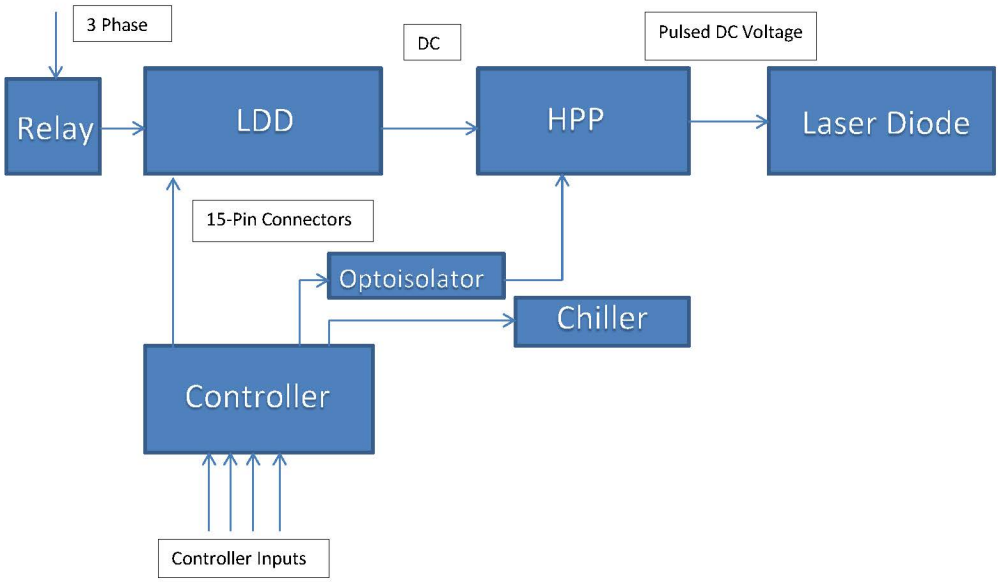


**Figure 2: LDD/HPP Laser Diode System**

The LDD/HPP controller uses the same hardware as the QCW system, but the difference lies in the code. Because this system requires two components to create the pulsed DC voltage, different code must be used to control each entity. The LDD and HPP must be separate in this system because the LDD is not able to pulse the amount of power it is outputting fast enough. Instead of the controller powering the diode driver and the pulser, it will power an external relay that will enable the LDD. This system uses an optoisolator between the controller and the HPP to create two separate ground planes. The optoisolator must be used to protect both incoming and outgoing signals from the electromagnetic noise created by the fast switching of the HPP.

**Final Design Information:**

- LCD's display values of output current, simmer current, and flow.
- Tripping one of the four interlocks will disable the voltage going to the QCW or LDD.
- The controller will not be affected by any interior or exterior electromagnetic noise.
- Output currents will be accurate with output DAC voltages.
- Controller will be able to power both circuit boards, the QCW, a chiller, and/or an external relay.
- All controller boxes will be visually identical.
- LCD's will be able to display interlocks when one is tripped.

**Design Constraints:**

- User friendly to almost anyone.
- At least four interlocks per controller.
- Controllers should be stackable or mountable to a rack.
- Output currents should be 200A on the QCW and 180A on the LDD/HPP.

**Risks:**

- Interlocks malfunctioning.
- Inaccurate current readings.

- Damage to laser diodes.
- Noise from system components interfering with board signals.
- Spikes in voltage on the PCB boards.

**Risk Mitigation Techniques:**

- Applying filters to interlock inputs and all other inputs to decrease noise.
- Adding digital and analog buffers.
- Inserting optoisolators.
- Pull-up and pull-down resistors on almost all power rails.
- Decoupling capacitors.
- Testing, more testing, and even more testing of all situations.

**Timeline:**

Fall 2014:

- Solder two QCW controller boards - Performed by Ryan Evans - 7/28 (Completed 7/29)
- Test both boards outside of box - Performed by Ryan Evans and Brandon Carr - 7/31 (Completed 7/31)
- Assemble box with all wiring - Performed by Ryan Evans - 8/5 (Completed 8/3)
- Finish testing of controller on "dummy" load - Performed by Ryan Evans and Brandon Carr - 8/10 (Completed 8/6)
- Test controller on system and install on laser diode - Performed by Ryan Evans and Brandon Carr - 8/15 (Completed 8/8)
- Completely build, test, and install LDD/HPP laser diode controller - Performed by Ryan Evans and Brandon Carr - 9/20 (Completed 9/23)
- Develop software for rotary encoder potentiometer - Performed by Ryan Evans and Brandon Carr – 10/10 (Completed 10/23)
- Test rotary encoder on newest QCW boards – Performed by Ryan Evans – 10/24 (Completed 10/28)
- Completely build, test, and install QCW laser diode controller - Performed by Ryan Evans and Brandon Carr – 11/21
- Completely build, test, and install LDD/HPP laser diode controller - Performed by Ryan Evans and Brandon Carr – 12/19

Spring 2015:

- Completely build, test, and install LDD/HPP laser diode controller - Performed by Ryan Evans and Brandon Carr – 2/20
- Remove 1st QCW controller and updated modifications – Performed by Ryan Evans – 3/6
- Remove 1st LDD/HPP controller and update with new modifications – Performed by Ryan Evans – 3/20
- Document a user's manual and technical detail – Performed by Ryan Evans– 4/30

**Device Testing and Validation:**

**Circuit Board:**

Design Requirements:

- Static shocks and shorting if electrical components on the board will not damage other components in the laser system.
- There will be no loose, unsoldered pins or shorts created by extra solder on the pins.
- 5V and 15V will be supplied to all of the correct pins on the board.

Testing of the PCBs used in the diode controllers is a critical step in producing a product that will be used for years to come. The first test done to the PCB is to make sure all of the pins after surface mounting are making good connections to the board. A dental pick will be used on the buffers, diodes, digital to analog converters (DACs), and the processor to make sure a solid solder joint was made. Testing the impedance between the power plane and the ground plane is an easy way to determine if there are any shorts between them. A short between these two planes will lead to failure of the entire board.

Once the testing of hardware components on the PCB is done, the next step is to power the board, upload the software, and begin to measure the outputs from the board to see if the inputs from the software match the outputs. One 5V power supply and one 15V power supply are mounted within the controller box to power the board. Vias were designed into the board layout to allow easy access to critical test points within the circuit. Each via's voltage is measured to ensure the correct voltages are being supplied to the correct rails within the board. If shorting between the planes occur, finding the short in the solder joints must be done before any other testing occurs. The voltage is measured by a multimeter to determine if there are any unwanted drops in voltage between the planes or traces. If there is an issue, the trace will be followed, and all of the voltages across all components on the trace will be checked to make sure any component failures are fixed before further testing occurs.

**Software/Hardware:**

Design Requirements:

- All interlocks will completely disable the laser system if any of them are triggered.
- The voltage outputs from the digital to analog converters will output 0-10V to the QCW or LDD/HPP.
- The rotary encoder will increment the driver current and set current in divisions of 0.05A per state change, at its maximum, it will not go higher than 200A, and at its minimum, it will not go lower than 0A.

The software is easily uploaded to our processor through our JTAG interface. With the software, outputs from the controller will be measured with a multimeter and compared to our software inputs. One of the first tests completed is the functionality of our interlocks. Interlocks will disable the entire system if any of them trip. To trip an interlock, all that needs to be done is to short the connection. If the number of the interlock disappears on the LCD when the connection is shorted, the interlock is working correctly. When the seven different interlocks are tripped and functionally working, the testing of the interlocks is complete. If an interlock does not trip on the display and the rest of the LCD is functioning correctly, there must be a break in the trace, an issue with the processor, or an issue within the code.

Testing the outputs of the controller to the Quasi-Continuous Wave driver (QCW), or Laser Diode Driver/High Power Pulser (LDD/HPP) is one of the most critical steps of the entire testing process. The DACs are the devices on the board that output a voltage that tells the QCW or LDD/HPP what current to output to the laser diode. The enable and ready signals are applied in the code, and the rotary encoder is adjusted up and down while a multimeter is placed on the output of the controller. The voltage should vary linearly with the increase in current from 0-10V. If this does not happen, a fault in the code or a bad connection could be the issue. A multimeter is used to accurately measure the output voltage from

the DACs. Once this test is completed, it is concluded that the board is ready to be installed in the controller enclosure.

To test the rotary encoder, a multimeter and the LCD were needed. The LCD was used to make sure that when the minimum or maximum value of the current was reached, the encoder did not go above or below the value or start over. This could also be seen through the multimeter. At its minimum, the output value of the current should be 0A, and at its maximum value, the current should be set to 200A. This test is similar to the testing of the DACs previously, but this time the voltage values between 0-10V had to correspond linearly to the values displayed on the LCD.

**Assembled Controller:**

There are a couple different stages in testing once the controller is fully assembled. To check the wiring and connection of all of the terminals, a multimeter is used to measure the different voltages at different points within the controller to make sure all voltages are correct. The same output test that was completed previously on the PCB is completed with the assembled controller. Interlocks are completely checked for loose connections or faulty cables, the LCD is checked for any output errors, and all of the same outputs from the controller are rechecked to make sure the wiring did not affect any of the outputs or create any unwanted shorts in the box.

**Load-Based:**

Design Requirements:

- The recreated current pulses will have a rise time and fall time less than 6-8 ns, and external and internal electromagnetic noise will not interfere with the pulse's profile and stability.
- Displayed current values on the LCD correspond directly to actual output current values through the 0.25-Ohm resistance.
- Internal and external electromagnetic interference (EMI) will not interfere with that functionality of the controller when implemented in the high-power, fast switching environment within the system.

Once it is shown that everything is working on the controller, a real-time test of the controller is completed in the lab where it will be used. Instead of connecting the controller to the laser diode before final testing has been completed, an array of smaller diodes is used to imitate the voltage drop associated with the actual laser diode. The array of diodes is soldered in series on a small through hole testing board. A QCW or LDD/HPP driver must be used at this point in testing because it must be shown that output current from wither of these drivers can be controlled by the controller accurately. A multimeter is placed across the diode array to measure the output voltage of the driver, and an oscilloscope is connected across a solid wire with about a 0.25-Ohm resistance to plot the output of the current pulse coming from the driver. The pulse must look clean without any bouncing after its rise and fall while also not having any variation in current from external noise in the lab. One of the reasons this test is done in the lab is because the amount of noise the controller will be exposed to. Electromagnetic interference from the high-powered switching and pulsing can create problems for controller electronics in the lab, which is one reason why the diode controllers needed to be revised.

The controller is not able to pulse the amount of current necessary to power the laser diode because the diodes used would not be able to handle the amount of power. A lower frequency pulse at a lower current must be used so the diodes do not burn. Experimental output current of the driver is manually calculated through Ohm's Law using the measured voltage across the resistance of the wire by the oscilloscope. This current value is then compared to the displayed current on the LCD of the

controller. These two numbers should match within half of an amp of each other. When the controller is functioning correctly with no errors, the setup is left to run for the rest of the day and the following next couple days. If no errors occur during this testing period, it is concluded the controller is stable enough to connect to the actual laser diode. After it is installed into the system, thorough testing of the controller on the system is performed by the researchers building and tuning the laser.

**Results:**

Currently, there have been two completed controllers that are functioning on two different laser diodes. The only issue found coming from testing of the completed controller is sporadic tripping of the interlocks in the lab. After further diagnosis of the problem, the noise coming from the lab was randomly triggering the interlock by creating small spikes in the voltage in the traces. This problem was fixed by adding a 56 pF capacitor to each of the inputs on the interlocks. No issues have occurred since.